Stratospheric Ozone Intrusion Exceptional Events

Uinta Basin, June 8-9, 2015 Case Study

Richard Payton, EPA Region 8

Exceptional Events Implementation Workshops

November 2016

Outline

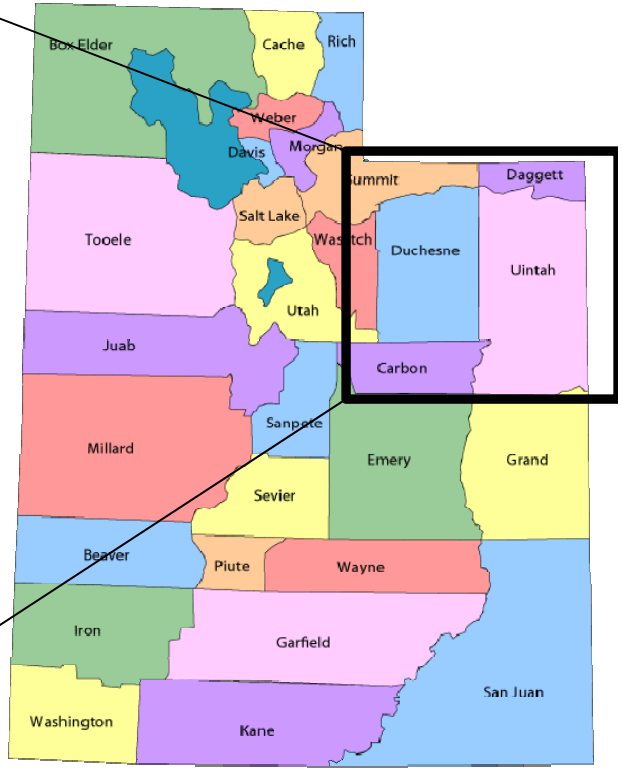
- Background
  - EE Rule and Tribal Monitoring
  - Stratospheric Ozone Intrusions
- Demonstration Elements
  - Conceptual Model
  - Event Occurred and Affected Air Quality
  - Clear Causal Relationship Between the Event and Exceedance(s)
  - Historical Data Comparison
  - Not Reasonably Controllable or Preventable
  - Natural Event
- Concluding Remarks & Discussion

Exceptional Events Rule and Tribes

- Clean Air Act required the EPA to promulgate rules to allow "the Governor of a State" to petition the Administrator to exclude air quality monitoring data
- 40 CFR 50.14(a)(1)(ii) provides that "A State, federal land manager or other federal agency" may request the Administrator to exclude data
- 2016 EE Rule Preamble, 81 FR 68224 explicitly continues the applicability of the exceptional event rule to tribal agencies operating ambient air monitors that produce regulatory data
  - Footnote 3 clarifies that "air agencies" includes state, local and tribal agencies
  - 2007 and 2016 rules extend support by the EPA to those tribal monitoring agencies requesting assistance in applying the rule

June 8 & 9, 2015 Stratospheric Ozone Event

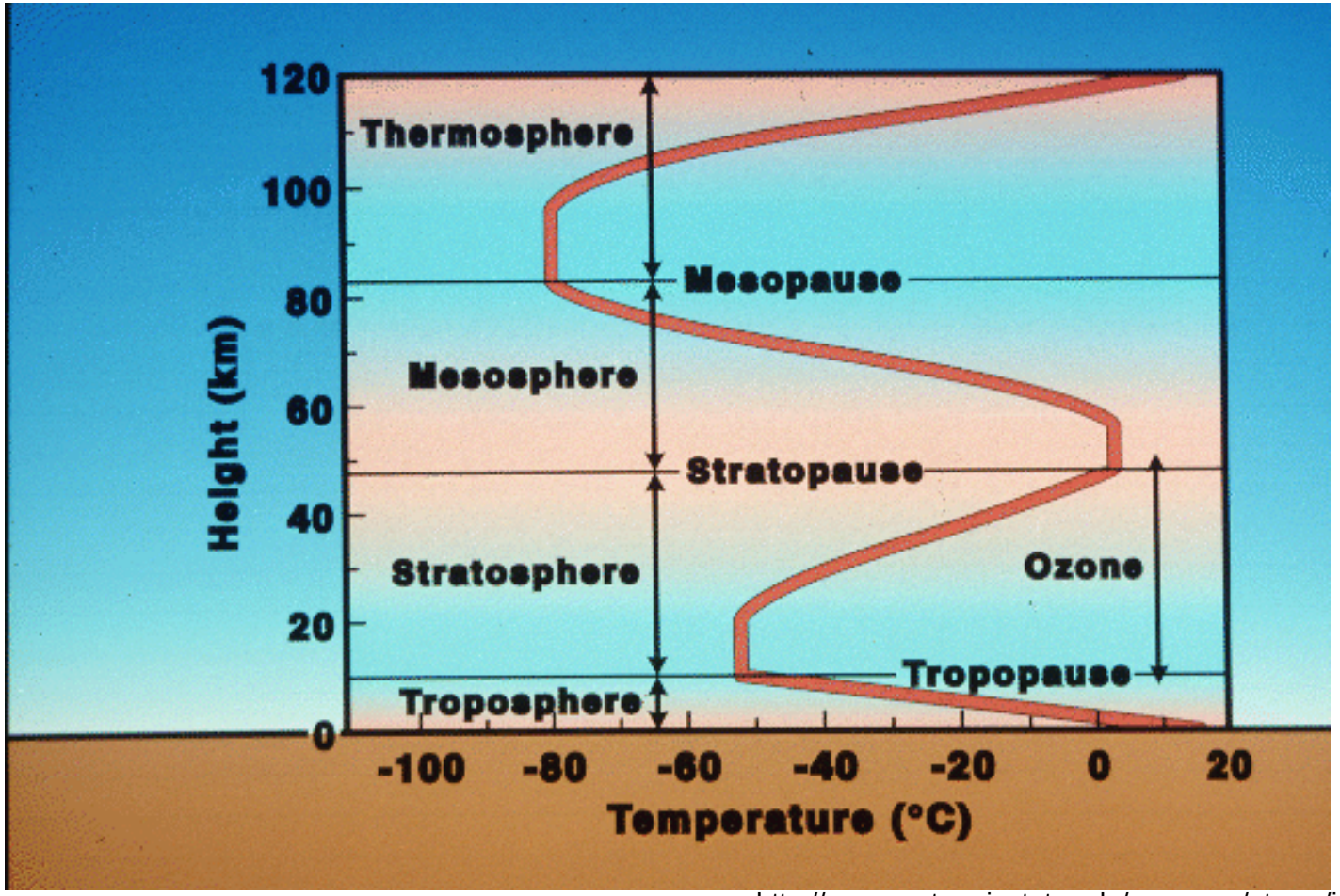
- The Ute Indian Tribe of the Uinta and Ouray Reservation operates 4 ozone monitors in the Uinta Basin Unclassifiable Area in eastern Utah



June 8 & 9, 2015 Stratospheric Ozone Event

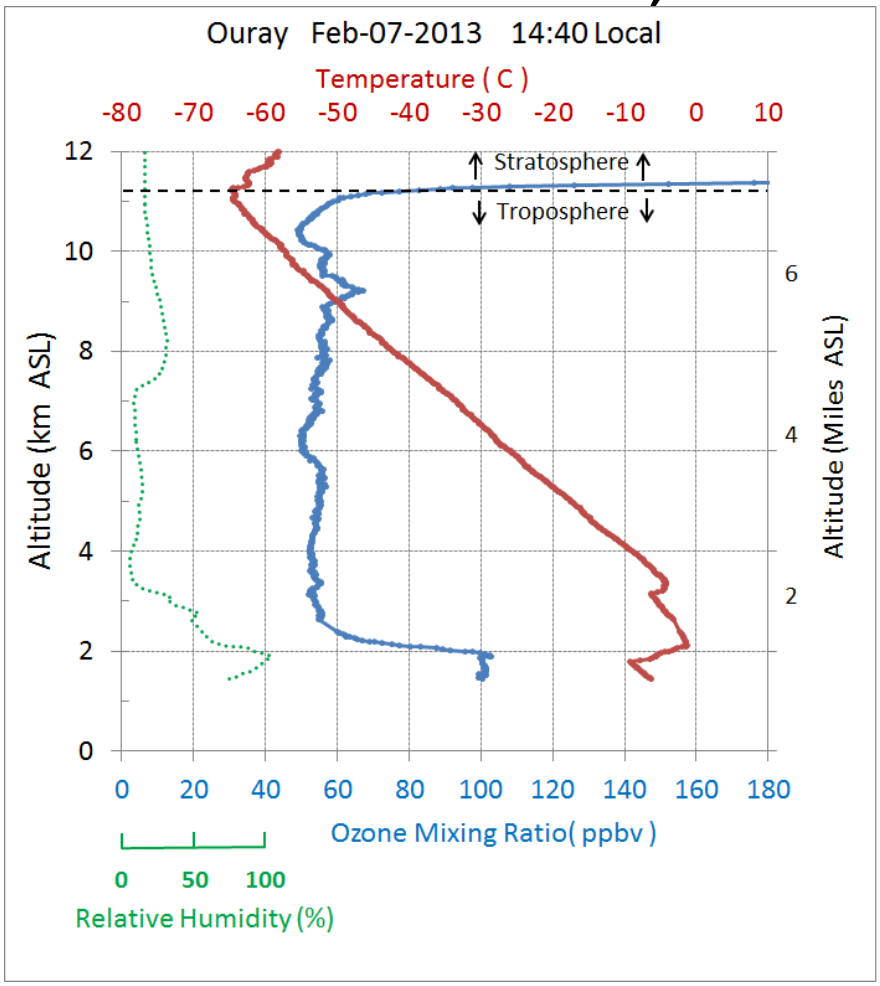
- 2013-2015 Ozone Design Values: 68 to 79 ppb
- 2014-2016 Preliminary Ozone Design Values: 71 to 81 ppb
  - EPA proposed breakpoint for Marginal-Moderate Classification: 81 ppb (November 2, 2016)
- Utah State University Bingham Research and Development Center identified June 8 & 9, 2015 as likely stratospheric ozone exceedances of the 2015 ozone NAAQS
- The Ute Indian Tribe asked EPA Region 8 for assistance in developing an exceptional event demonstration for the two day event
- That demonstration provides the case study for today

Structure of the Atmosphere



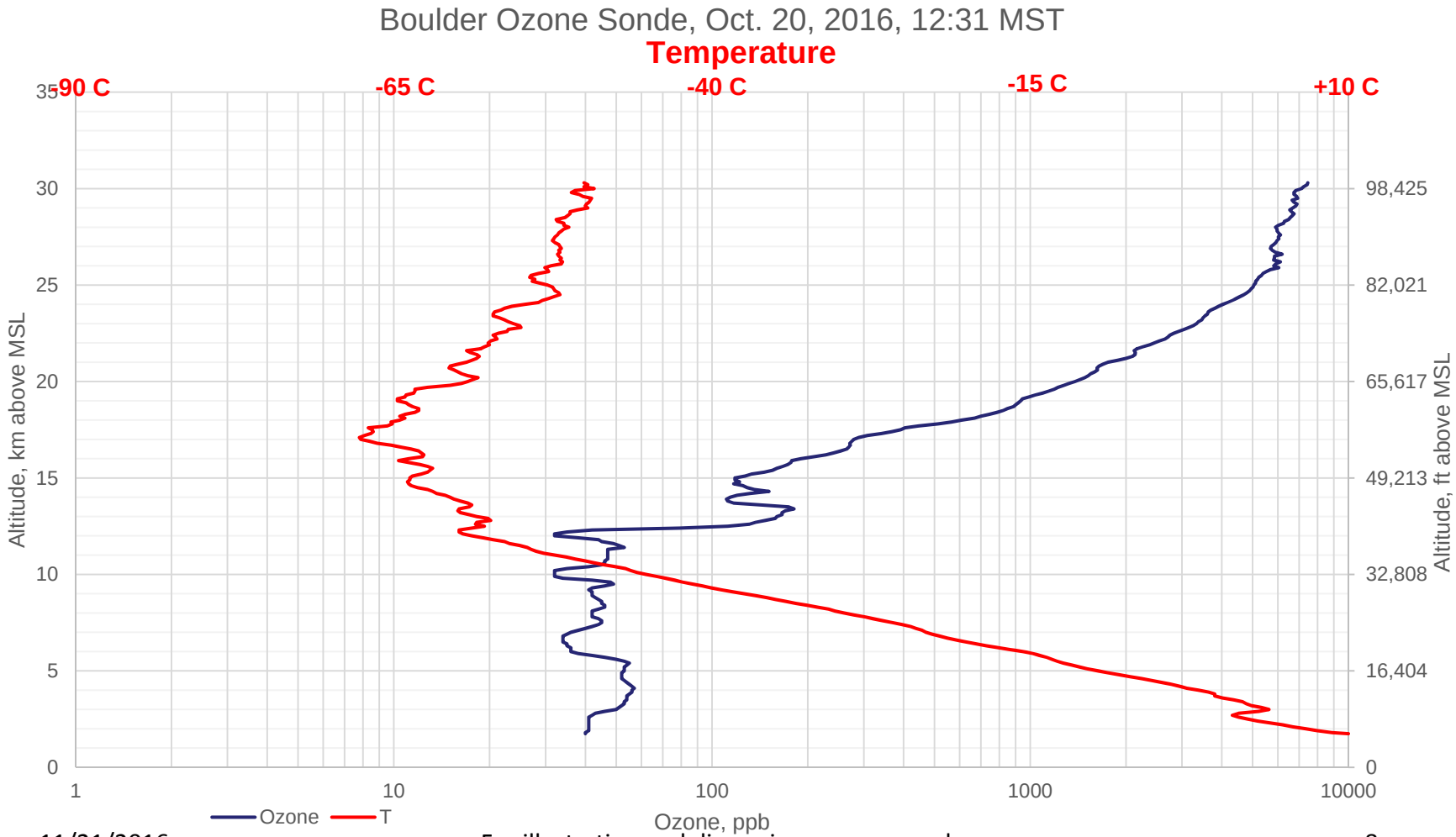
http://www.meteor.iastate.edu/gccourse/atmos/images/image7.gif

Uinta Basin Ozone Sonde, February 7, 2013



NOAA Earth Systems Research Laboratory, Global Monitoring Division
ftp://ftp.cmdl.noaa.gov/ozwv/

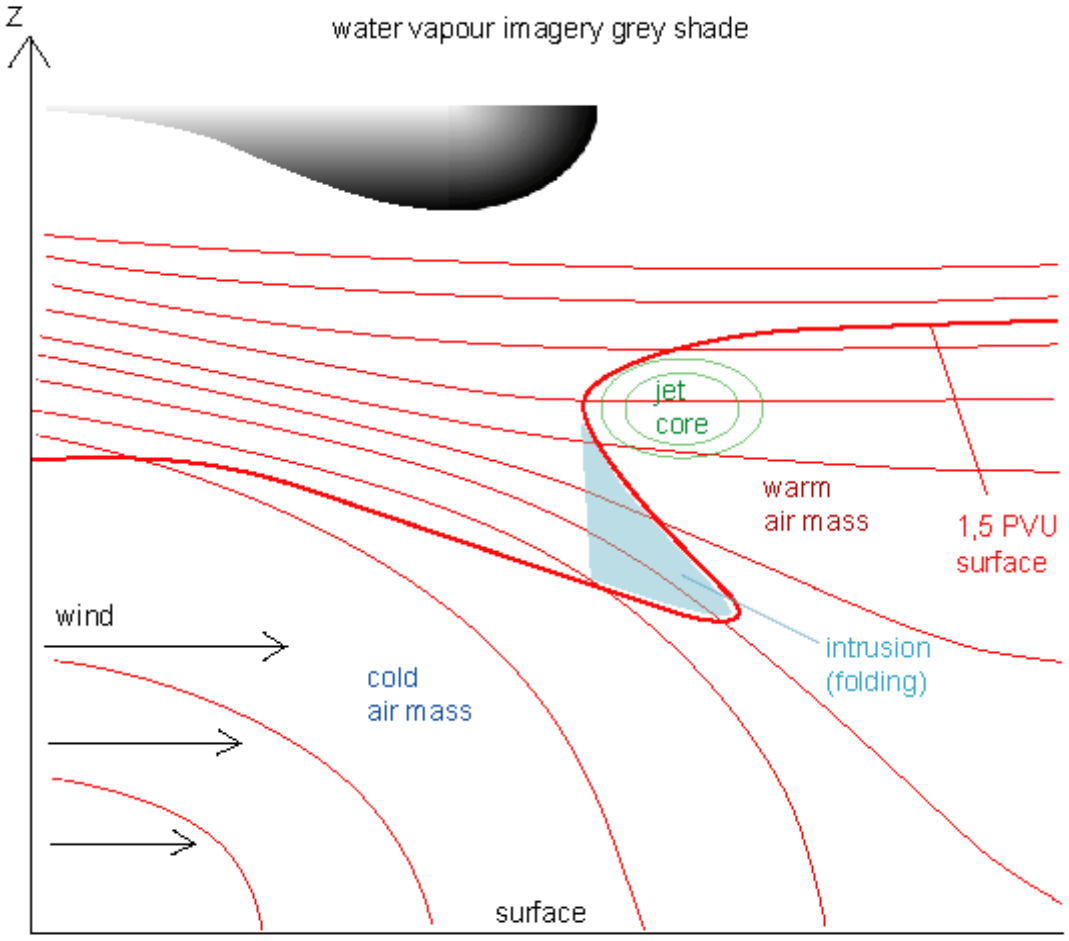
Boulder, Colorado Ozone Sonde, Oct. 20, 2016, 12:31 pm MST



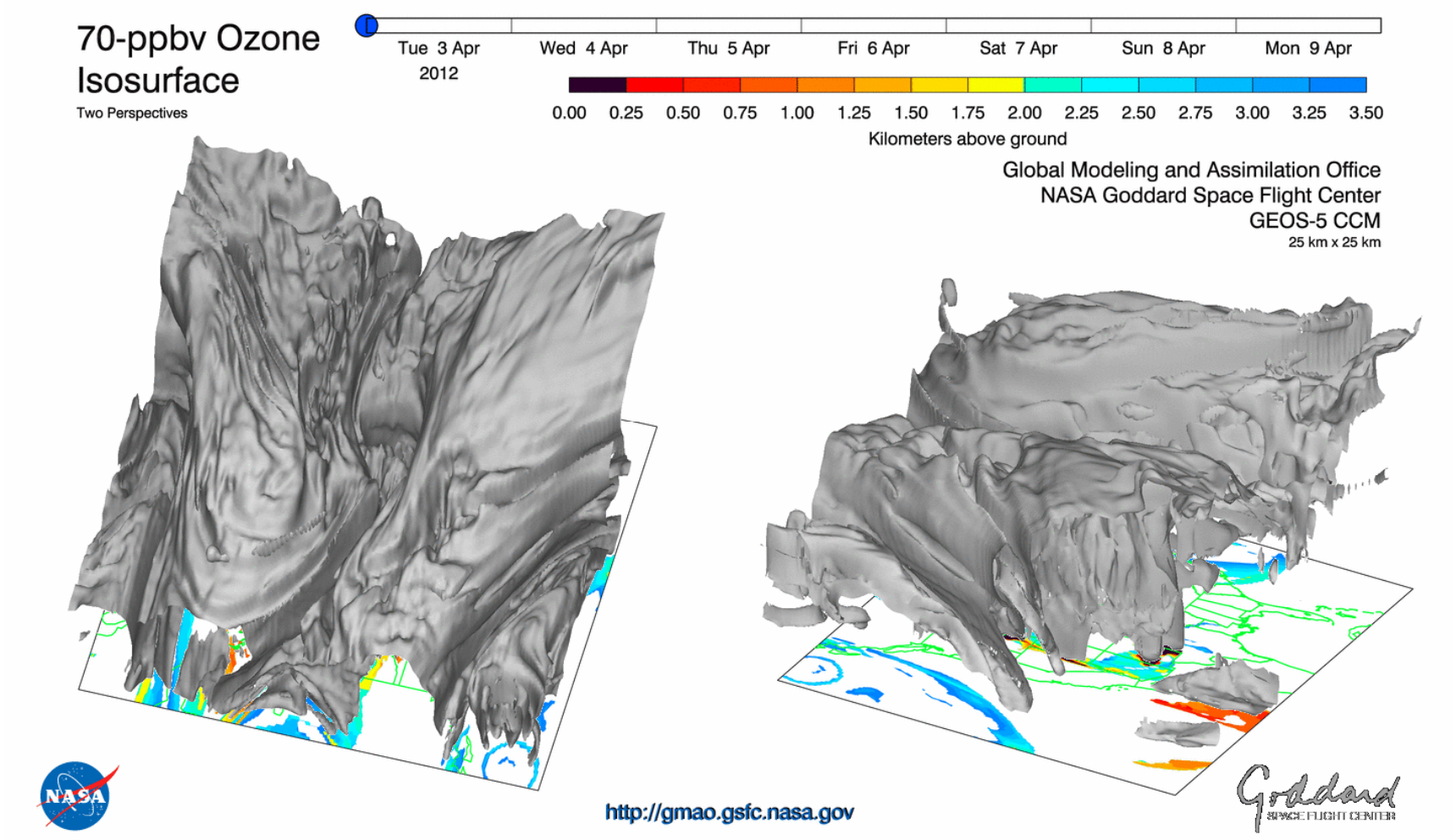
For illustration and discussion purposes only

NOAA Earth Systems Research Laboratory,
Global Monitoring Division
ftp://ftp.cmdl.noaa.gov/ozwv/

Structure of a Tropopause Fold



http://www.eumetrain.org/data/3/33/para3.htm


70-ppbv Ozone Isosurface
Two Perspectives
Tue 3 Apr 2012
Wed 4 Apr
Thu 5 Apr
Fri 6 Apr
Sat 7 Apr
Sun 8 Apr
Mon 9 Apr
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50
Kilometers above ground
Global Modeling and Assimilation Office
NASA Goddard Space Flight Center
GEOS-5 CCM
25 km x 25 km
http://gmao.gsfc.nasa.gov
Goddard
SPACE FLIGHT CENTER

SI EE Demonstration Elements

- Conceptual Model
- Clear Causal Relationship
  - Comparison to Historical Data
  - Meteorology
  - Evidence of Stratospheric Intrusion
  - Clear Causal Relationship Conclusion
- Natural Event
- Not Reasonably Controllable or Preventable
- Conclusion

June 8-9, 2015 Conceptual Model

- Uinta Basin is a winter ozone area
  - Historically, high ozone Dec-March, non-exceedance ozone April-November
- 2015: No winter snow/ozone; highest ozone June 8 & 9
  - June 8 & 9 ozone in Uinta Basin of Utah highest June levels ever observed at most monitors
- June 2-June 10, 2015 relatively high ozone (8-hour average 60 to 77 ppb) at numerous intermountain west high elevation (6,641 to 10,445 feet) ozone monitors
- Beginning June 4, an upper level low pressure system slowly moved east from California to the Great Lakes
  - June 8 & 9, an elongated trough extended from the Great Lakes low to the Pacific coast
- Satellite based ozone measurements showed elevated total atmospheric column ozone coincident with the elongated trough, particularly over Utah
- Stratospheric ozone intrusion therefore caused the ozone exceedances in the Uinta Basin on June 8 and 9, 2015, not local emissions and normal photochemistry

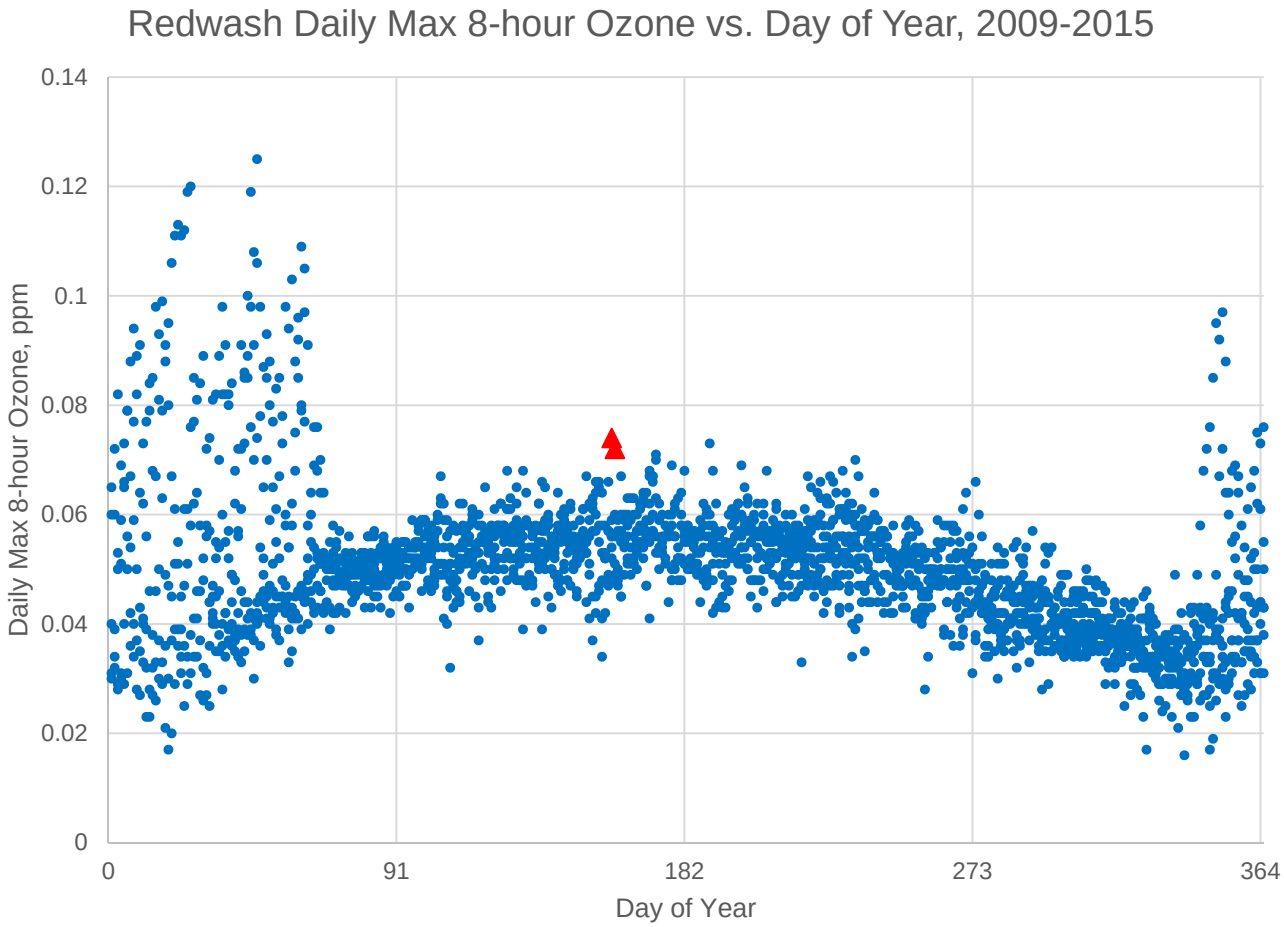
Clear Causal Relationship: Comparison to Historical Data

- Calculated standard suite of statistics for June 8 & 9:
  - Percentiles and Ordinal ranks
    - Considering all data and just April-June data
  - Means
    - Considering all data and just April-June data
  - Standard Deviations
    - Considering all data and just April-June data
- Used Graphical comparisons

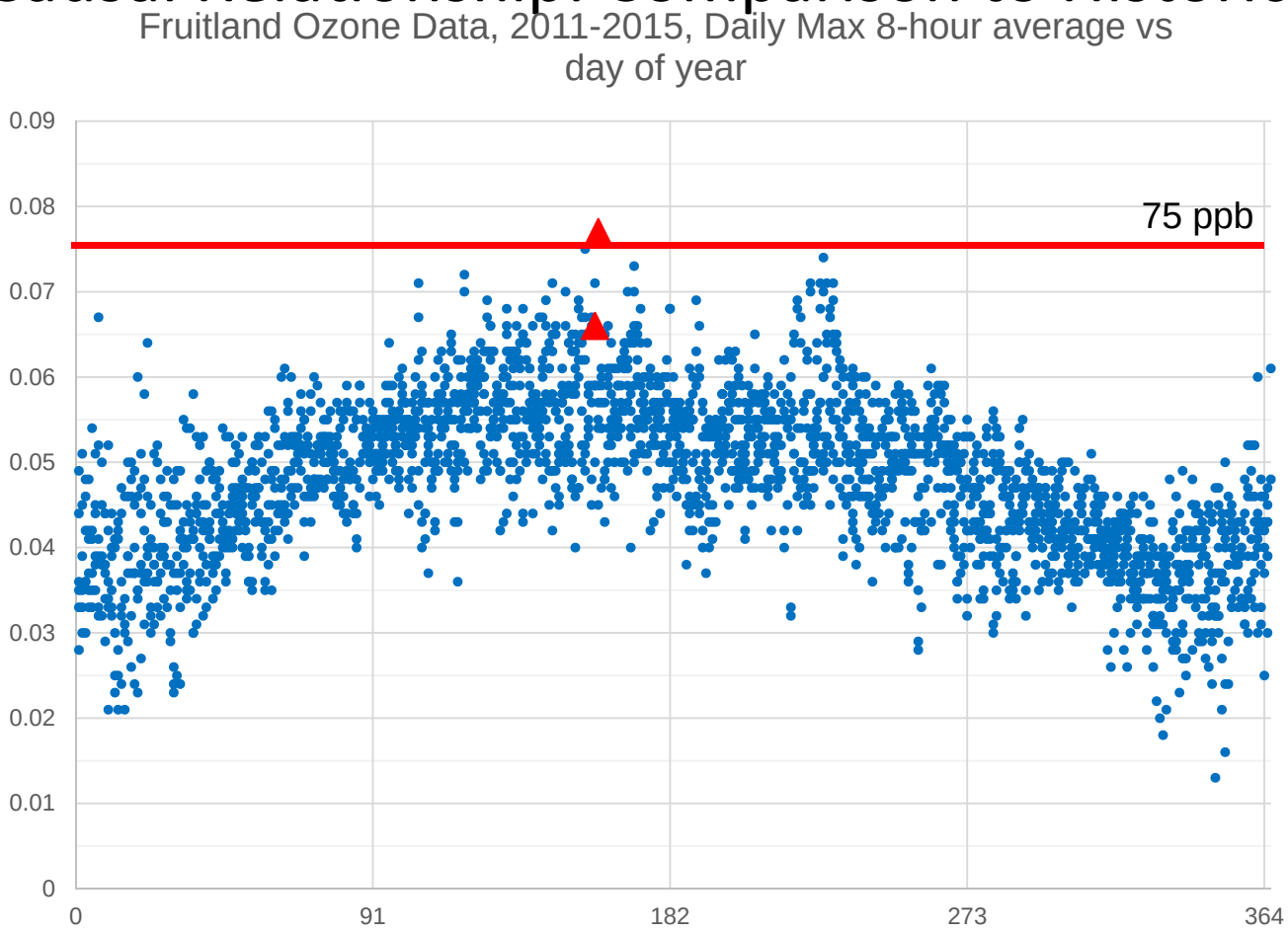
Ordinal Ranking of June 8 & 9, 2015 Ute Indian Tribe Data, April-June Historical

Site	Data Period	June 8 Ordinal Rank	June 9 Ordinal Rank
Ouray	2010-2015	4th of 514	5th of 514
Redwash	2010-2015	1st of 542	2nd of 542
Myton	2011, 2013-2015	2nd of 364	1st of 364
Whiterocks	2011, 2013-2015	1st of 362	2nd of 362

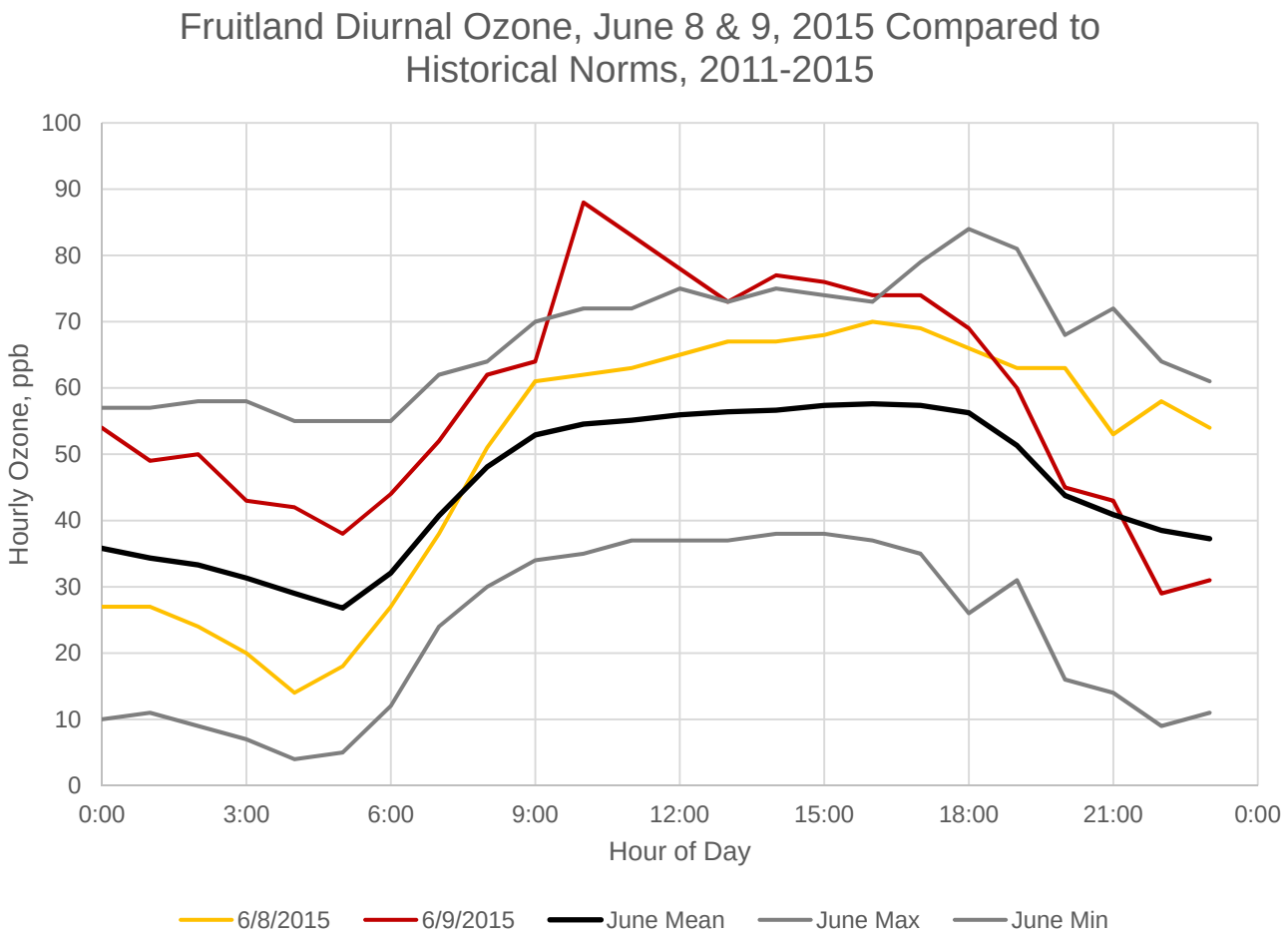
Clear Causal Relationship: Comparison to Historical Data



Clear Causal Relationship: Comparison to Historical Data



Clear Causal Relationship: Comparison to Historical Data



Comparison to Historical Data Summary

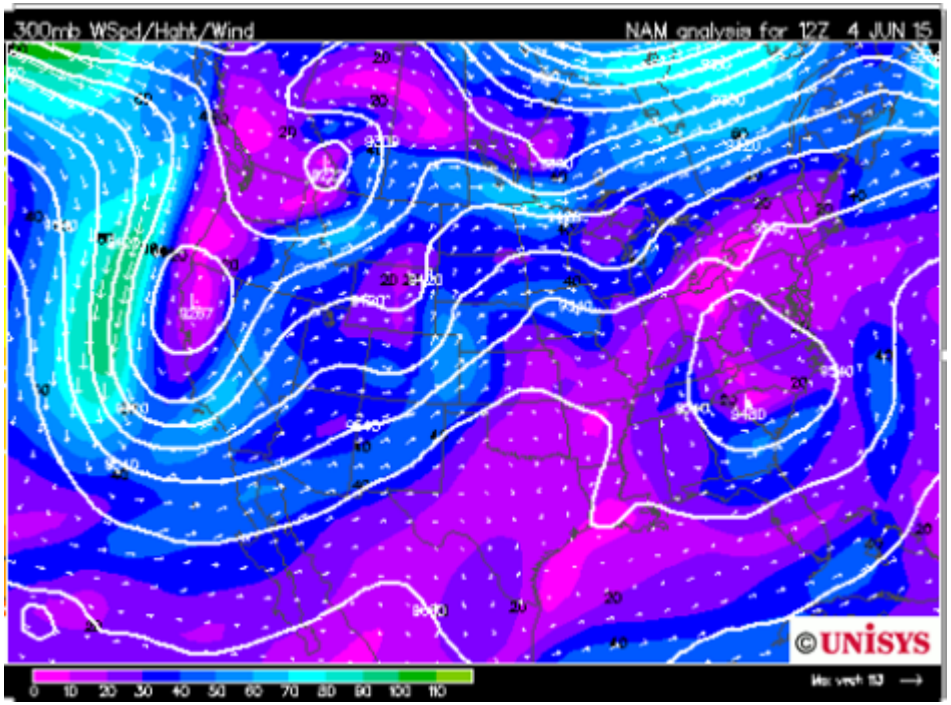
- June 8 & 9, 2015 were the 1st and 2nd highest April-June ozone days at 3 of the 4 Ute Indian Tribe ozone monitors, considering data back to 2010
- The diurnal profile for ozone on June 8 & 9, 2015 showed anomalous high ozone before noon, and had hours of higher than historically observed ozone throughout the day
- Establishes context for the remaining evidence

Clear Causal Relationship: Meteorology

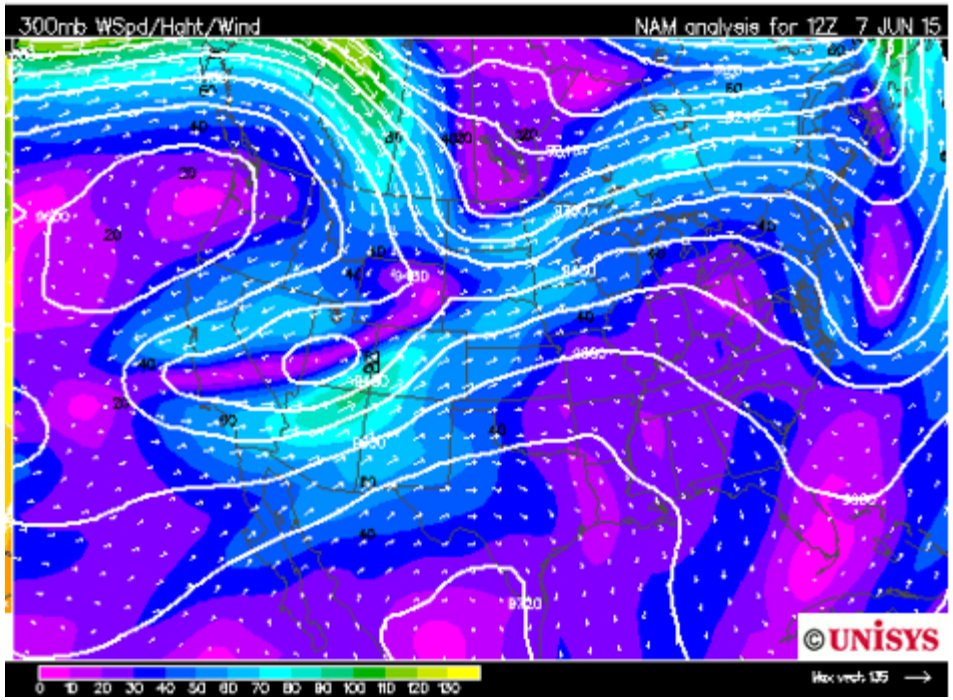
- June 8 & 9, 2015 surface winds were light and variable
- Temperatures were relatively high, mid-80s
- Upper Air Charts
- Can we find a method to compare June 8 & 9 ozone and meteorology to similar historical days?

June 4 and June 7 Upper Air Charts

June 4, 5:00 am MST
Trough down the Pacific coast



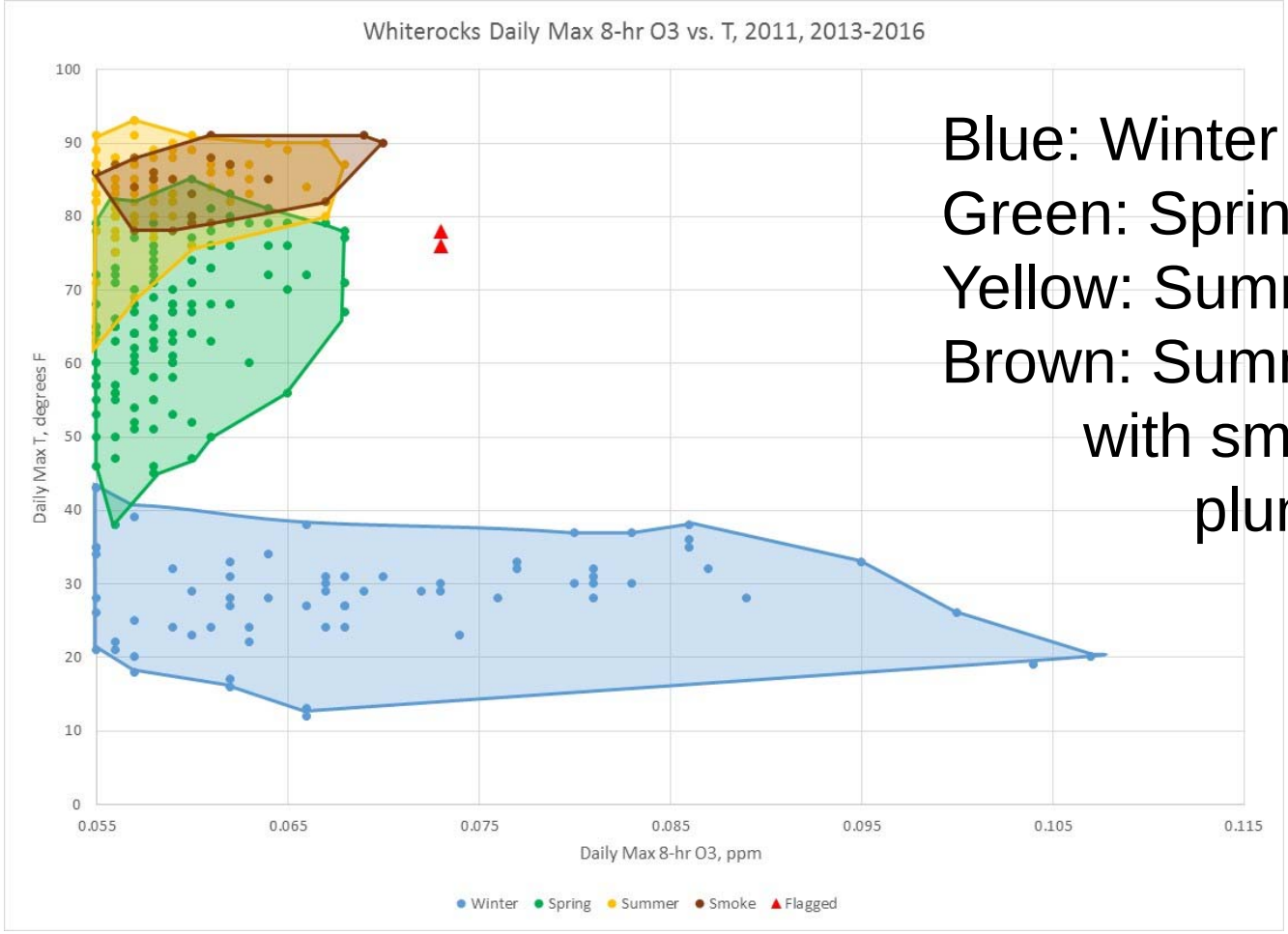
June 7, 5:00 am MST, Trough in south central Canada, narrow extension to the Pacific coast



Comparing Meteorology and Ozone to Historical Days

- Options?
- Multivariate regression models
  - Consider numerous meteorology variables, select optimum set for predictive power
  - Challenges
    - Would want to do seasonal models, exclude winter ozone days
    - Regression coefficients tend to overly influenced by “normal days”, 40 to 60 ppb with little or no local photochemistry
    - Regressions tend to have greatest predictive strength at the middle of the distribution, weakest at the top
    - Here, we have measured ozone outside the range of historical days, may be decoupled from the historical data set
- As an alternative, can we do a binary comparison of ozone and key met parameters?

Binary Comparison of Daily Max 8-hour O_3 and T



Blue: Winter
Green: Spring
Yellow: Summer
Brown: Summer with smoke plumes

Clear Causal Relationship: Evidence of Stratospheric Intrusion

- Observations
  - Satellite Total Column Ozone and Carbon Monoxide
  - Twice daily upper air balloon soundings (T and RH)
- Models
  - Forecast and reanalysis models of
    - Tropopause Height
    - Atmospheric Chemistry
- Characteristics of Stratospheric Air
  - Elevated O_3
  - Low in carbon monoxide, relative humidity
  - Elevated IPV, PT

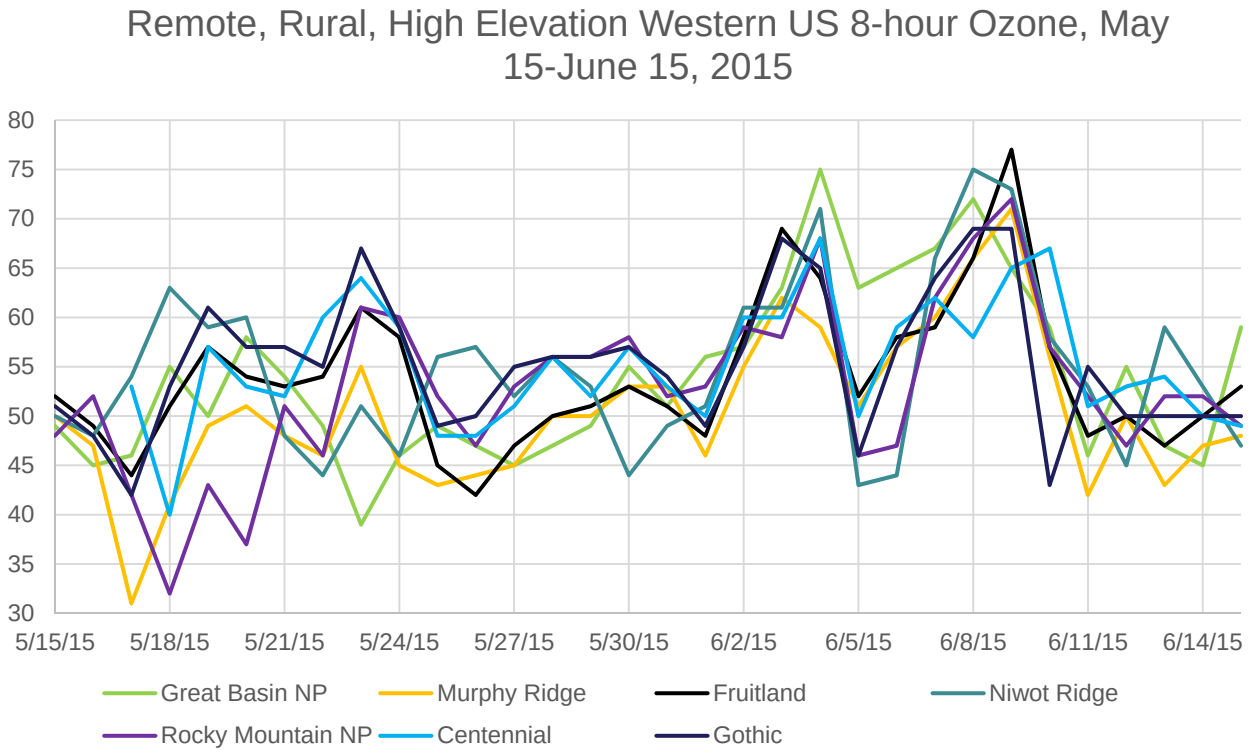
Clear Causal Relationship: Evidence of Stratospheric Intrusion

- Elevated IPV, PT*
  - **IPV**: "IPV [isentropic potential vorticity] is a proxy for atmospheric spin and is a conservative property [*A property with values that do not change in the course of a particular series of events*] with values of up to two orders of magnitude [100 times] greater for stratospheric air than that of tropospheric air (from Shapiro 1980). Therefore, IPV can serve as a tracer of stratospheric air. One unit of IPV (1-PVU) typically represents the tropopause (Shapiro 1980), and as one ascends beyond the tropopause into the stratosphere, the value of IPV increases correspondingly"
  - **PT**: "Potential temperature is "the temperature that an unsaturated parcel of dry air would have if brought adiabatically and reversibly from its initial state to a standard pressure, p0, typically 100 kPa" (or 1000 mb) (American Meteorological Society 2010). Stratospheric air has much higher values of potential temperature than that of tropospheric air. As stratospheric air penetrates the troposphere, its potential temperature is higher than that of tropospheric air surrounding the SI."

**Exceptional Event Demonstration Package for the Environmental Protection Agency, Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012*, Wyoming DEQ, June 2013
https://www.epa.gov/air-quality-analysis/exceptional-events-documents-ozone-wyoming

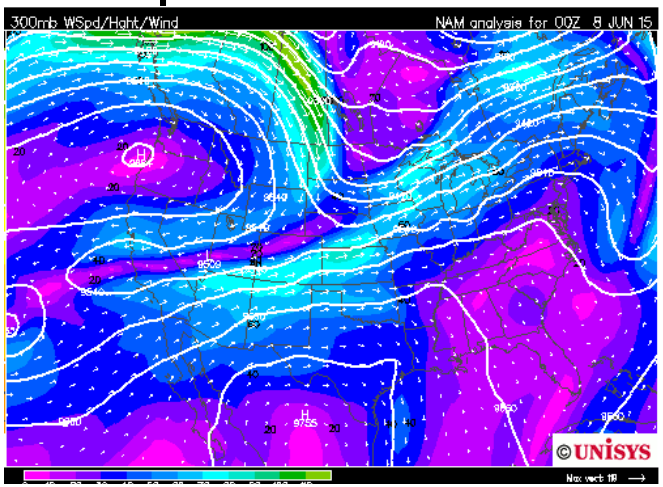
Clear Causal Relationship: Monitor Data

- Diurnal and seasonal ozone profiles
- Spatial distribution of ozone

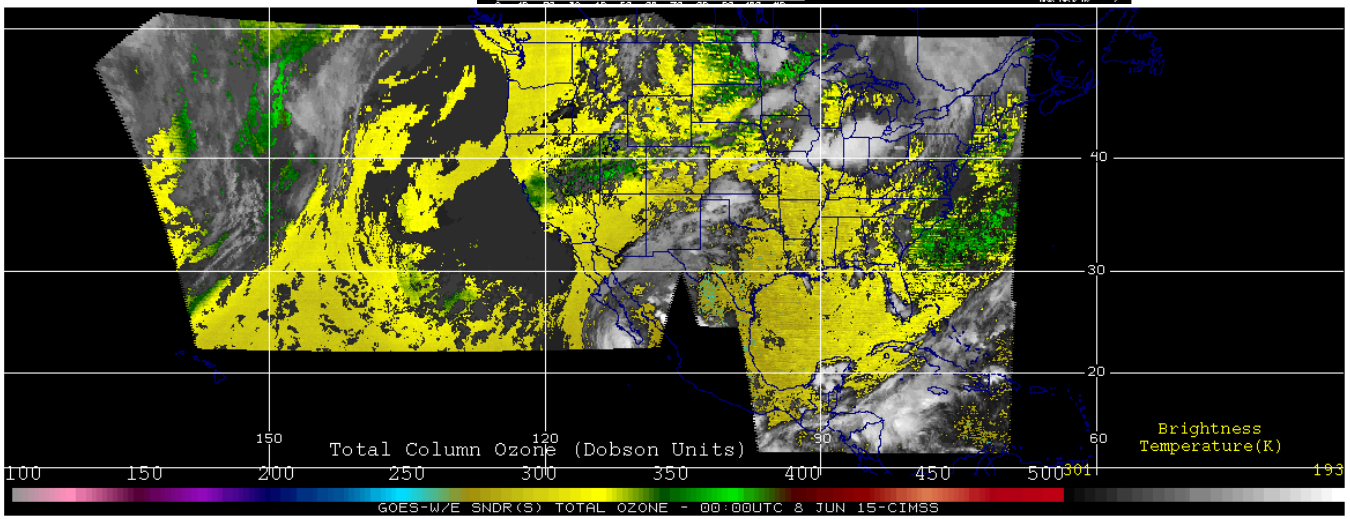


Clear Causal Relationship: Observations: Total Column O_3

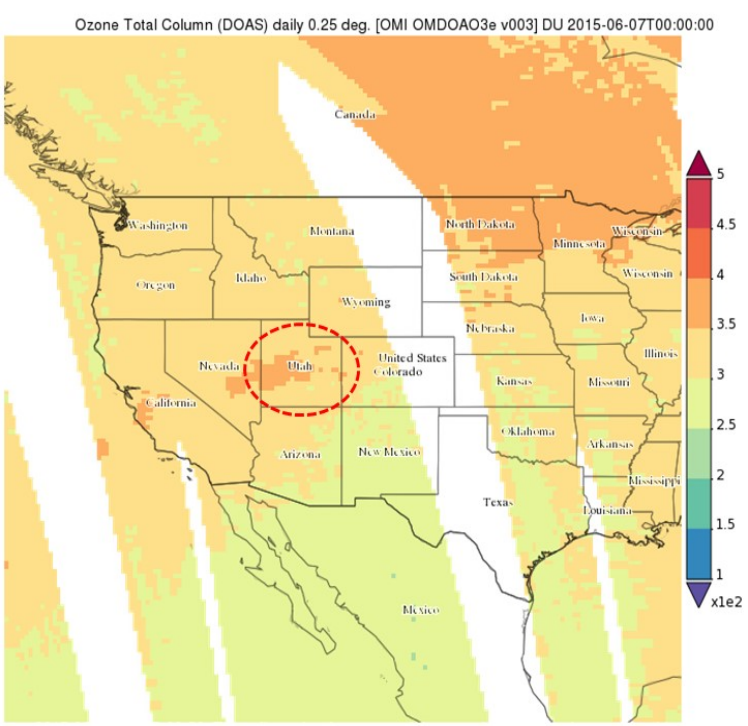
Elevated Total Column O_3 Coincident with Elongated Trough

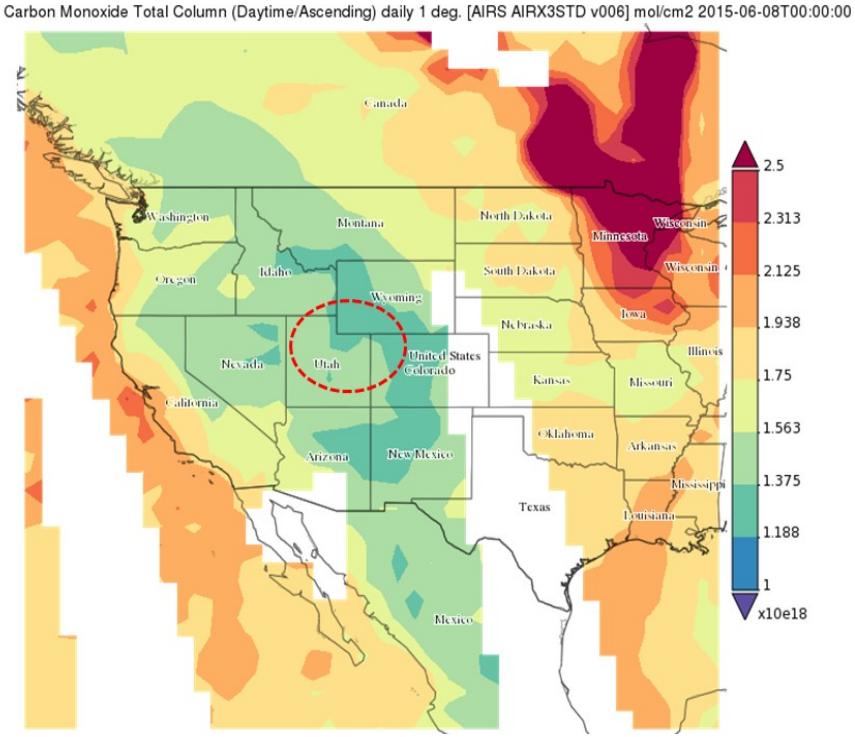


http://weather.unisys.com/archive/eta_init/
https://cimss.ssec.wisc.edu/goes/rt/viewdata.php?product=o3_us



Clear Causal Relationship: Observations: Total Column O_3 & CO





http://giovanni.gsfc.nasa.gov/giovanni/

Clear Causal Relationship: Observations: Upper Atmosphere Soundings

University of Wyoming
College of Engineering
Department of Atmospheric Science

http://weather.uwyo.edu/upperair/sounding.html

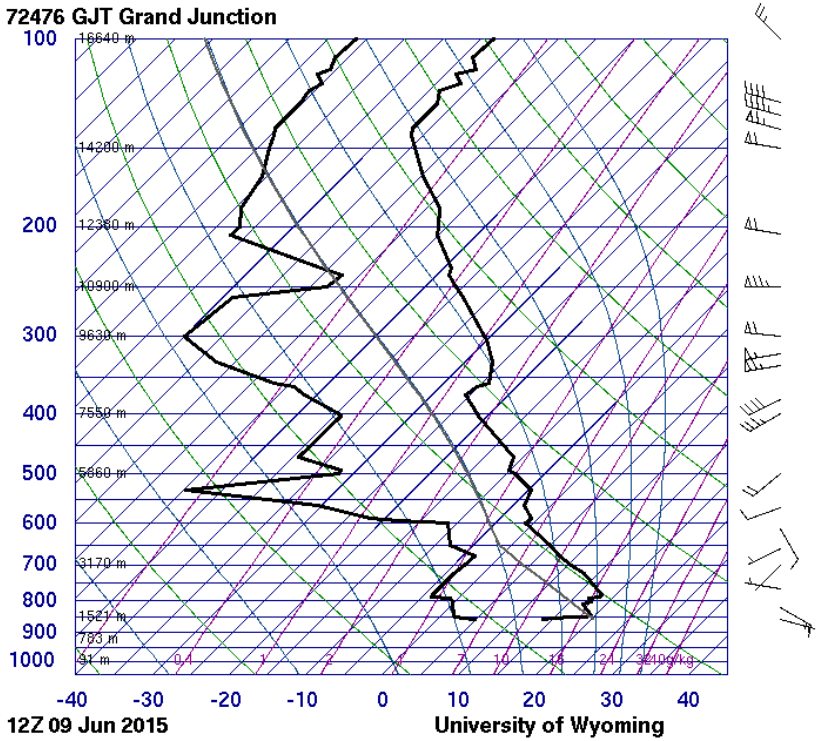
http://vortex.plymouth.edu/myo/upa/raobplt-a.html

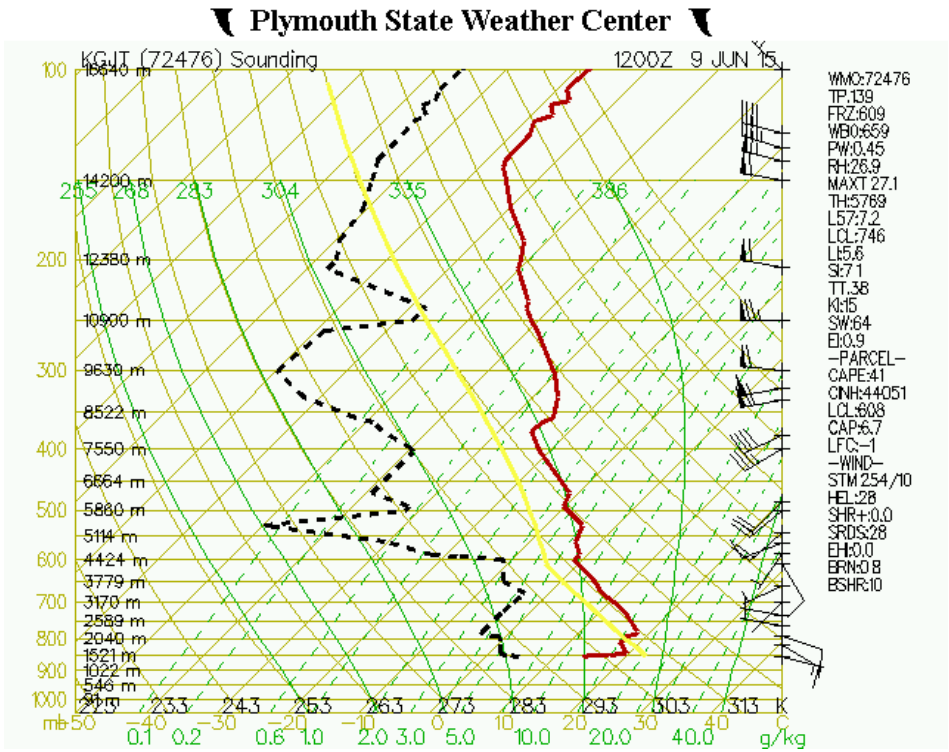
Region	Type of plot	Year	Month	From	To	Station Number
North America	GIF: Skew-T	2015	Jun	06/12Z	10/12Z	78762

Click on the image to request a sounding at that location or enter the station number above.

Include frost point calculations.
Recalculate Data

Clear Causal Relationship: Observations: Upper Atmosphere Soundings





http://weather.uwyo.edu/upperair/sounding.html

http://vortex.plymouth.edu/myo/upa/raobplt-a.html

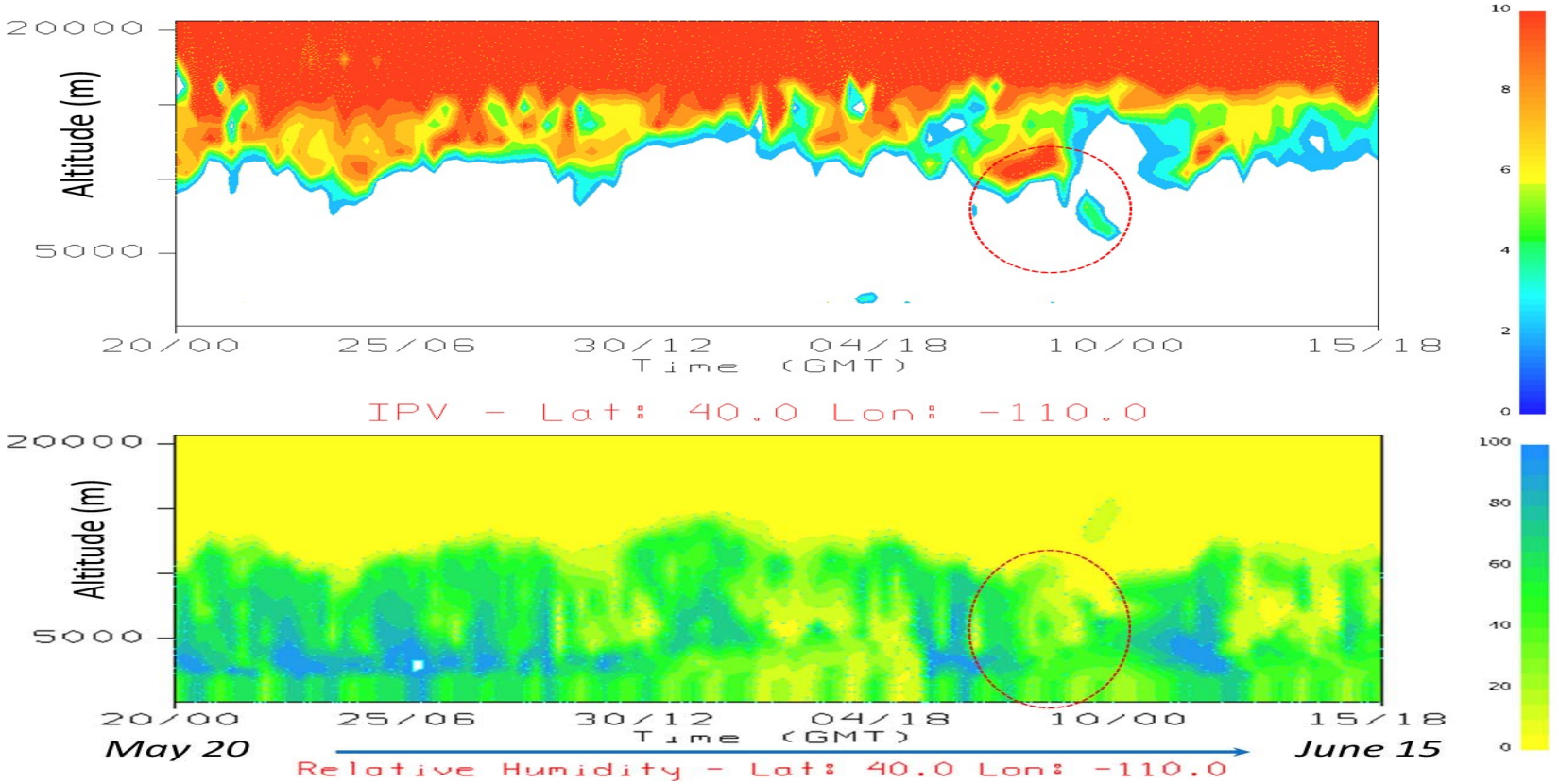
Clear Causal Relationship: Models

- Model Types
  - Forecast vs. Reanalysis
    - Forecast is predictive, extrapolating from a set of observations
    - Reanalysis is retrospective, combining forecast and observations to build best representation of a point in time
  - Meteorology vs. Chemistry
    - Meteorology can look at IPV, PT intrusions, with low RH, tropopause height
    - Chemistry can predict ozone, CO concentrations associated with intrusions

Clear Causal Relationship: Models: Meteorology

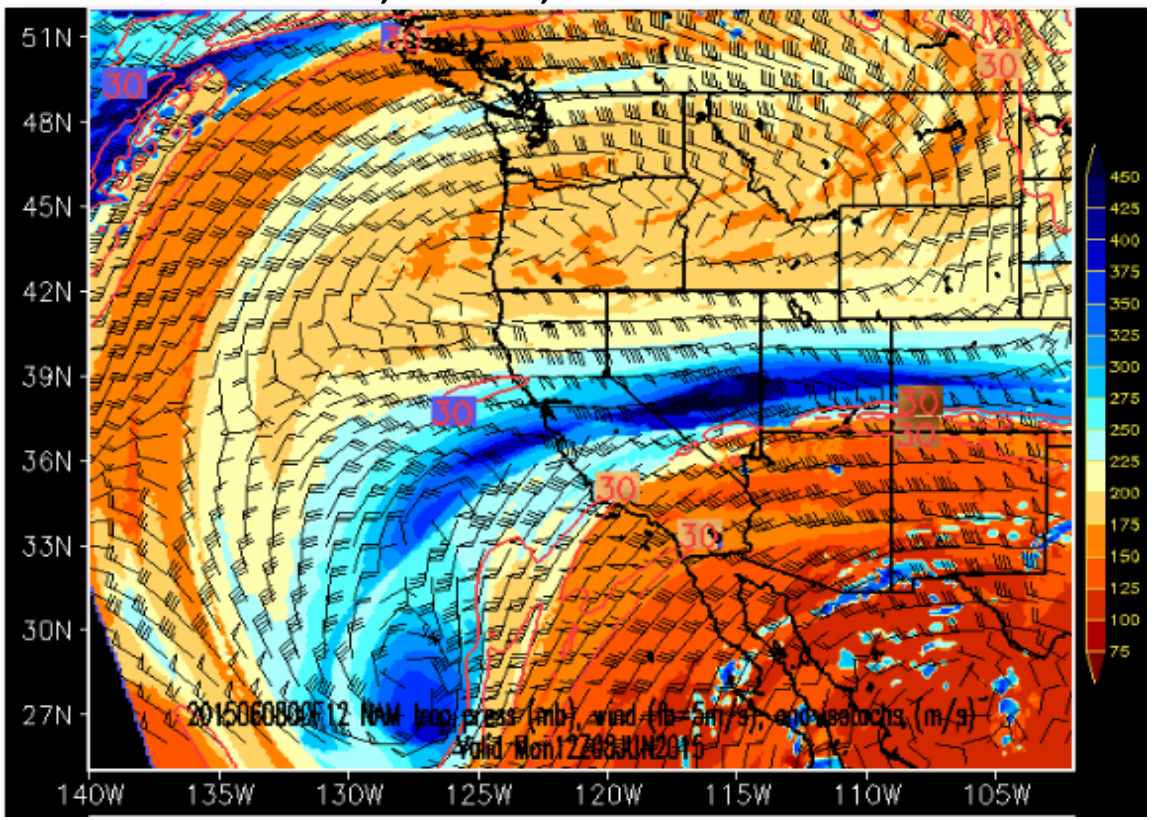
- Forecast Models
  - NAM: North American Mesoscale Model
  - GFS: Global Forecast System
  - RAP: Rapid Refresh
- Reanalysis Models
  - NARR: North American Regional Reanalysis
- Data Archive
  - Digital data files at https://www.ncdc.noaa.gov/data-access/model-data/model-datasets
  - Generally need a data viewer (IDV) to visualize the modeled data
    - IDV: Integrated Data Viewer http://www.unidata.ucar.edu/software/idv/

Clear Causal Relationship: Models: NAM IPV and Relative Humidity, May 20-June 15, 2015



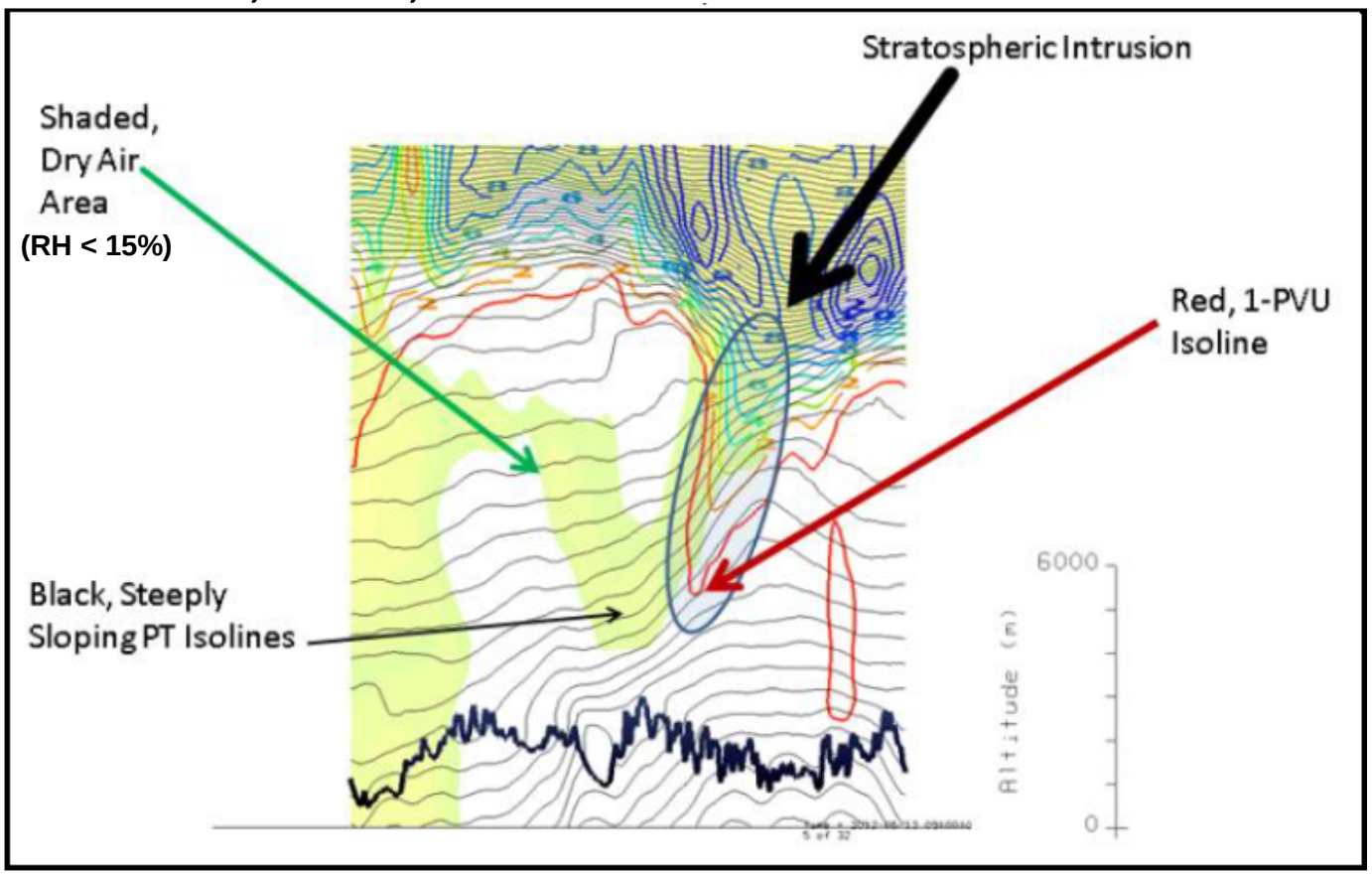
Investigation of Possible Ozone Exceptional Events in June 2015 in the Uintah Basin,
Tran, Huy, Seth Lyman, Trang Tran, Marc Mansfield, Brigham Entrepreneurship & Energy Research Center, Utah State University, April 2016.

Clear Causal Relationship: Models: NAM Tropopause Height, June 8, 2015, 5:00 am MST



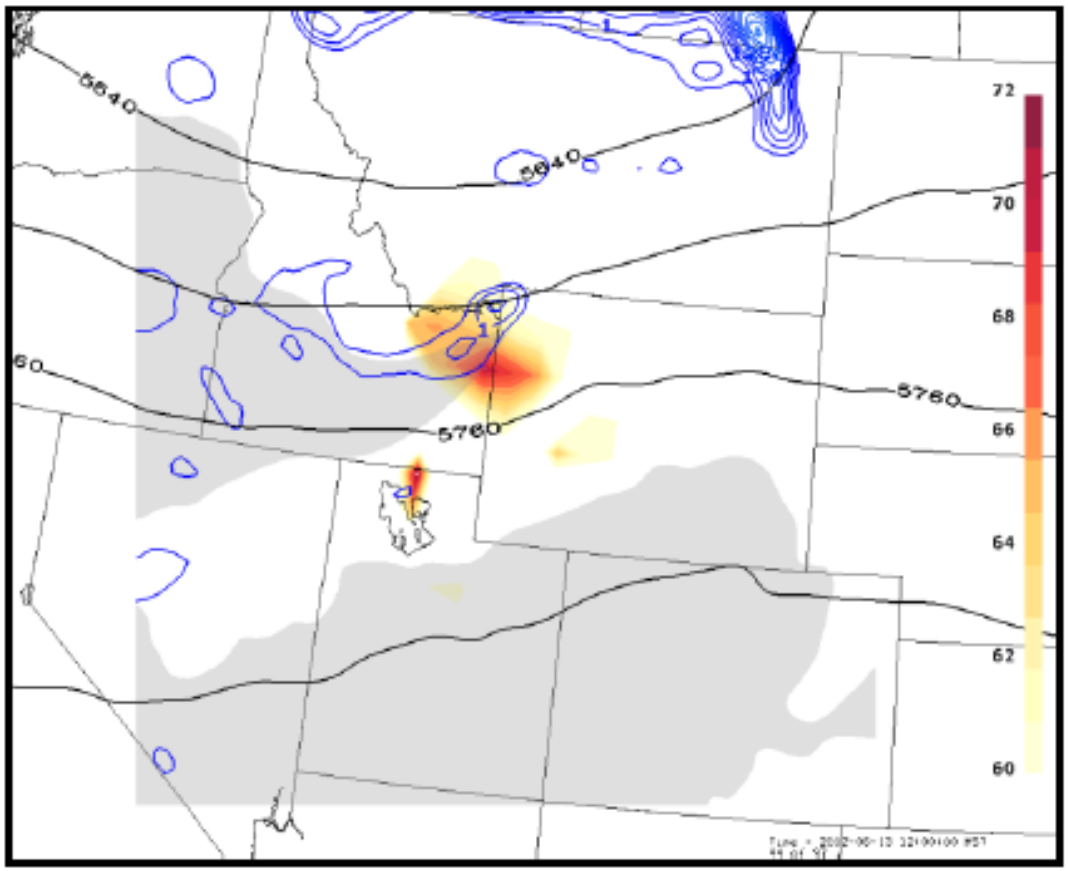
University of Utah, Horel Research Group archived data

Clear Causal Relationship: Models: RAP IPV, PT and RH, June 13, 2012, 9:00 am MST



Exceptional Event Demonstration Package for the Environmental Protection Agency
Big Piney and Boulder, Wyoming Ozone Standard Exceedances June 14, 2012, Wyoming DEQ, June 2013.

Clear Causal Relationship: Models: RAP 600 mb height (m, black),
IPV > 1 at 625 mb (blue), 625 mb RH < 30% (grey) and max 8-hr O3 (orange) June 13, 2012



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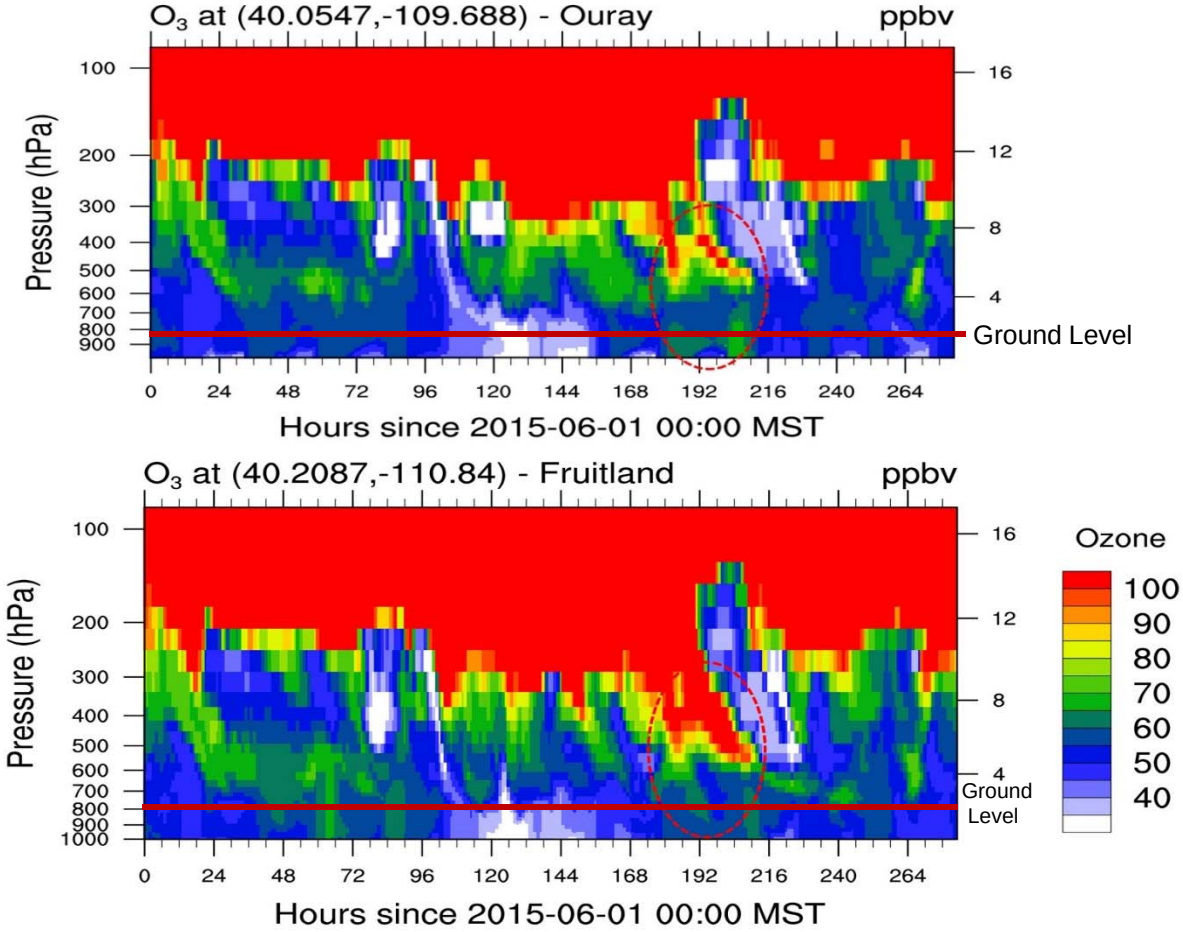
Clear Causal Relationship: Models: Chemistry

- Chemistry Models
  - **MOZART**: Model for OZone And Related chemical Tracers (NCAR)
  - **GEOS-Chem**: Global chemical transport model (NASA-Harvard-Dalhousie)
  - **RAQMS**: Real-time Air Quality Modeling System (NASA-NOAA-University of Wisconsin)

Clear Causal Relationship: Chemistry Models: GEOS-Chem Modeling of Ozone Above Uinta Basin, June 1-12, 2015



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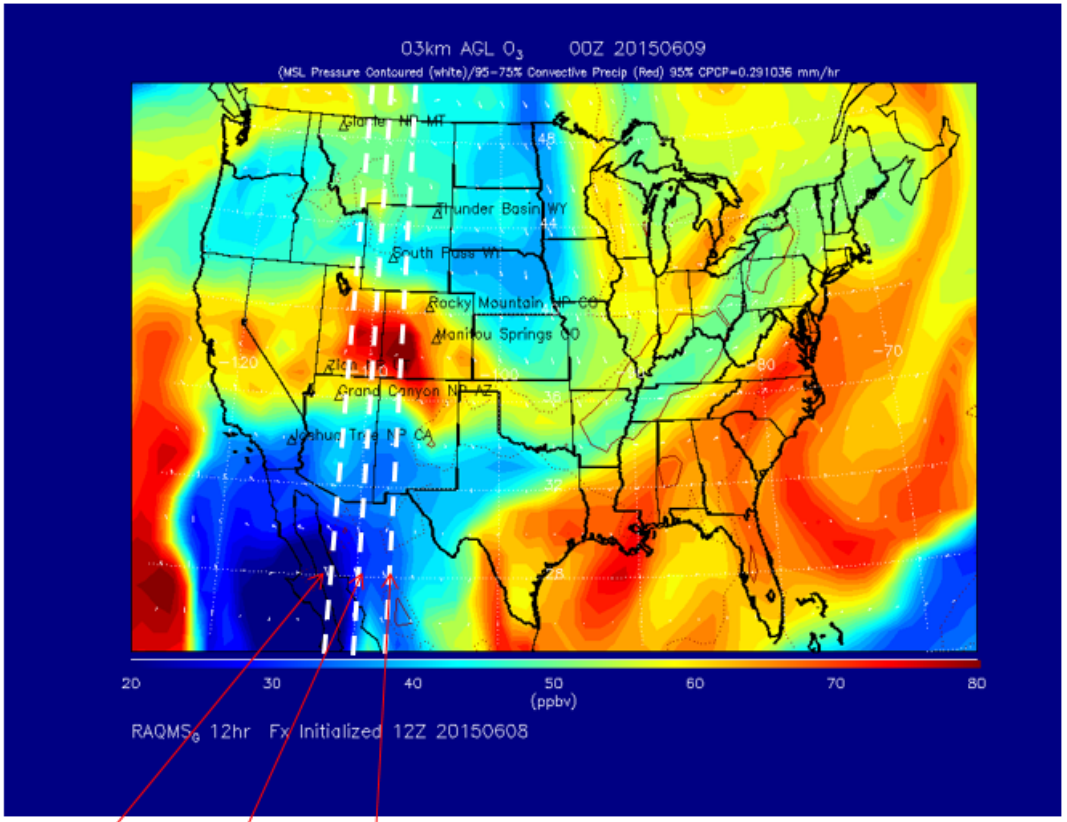
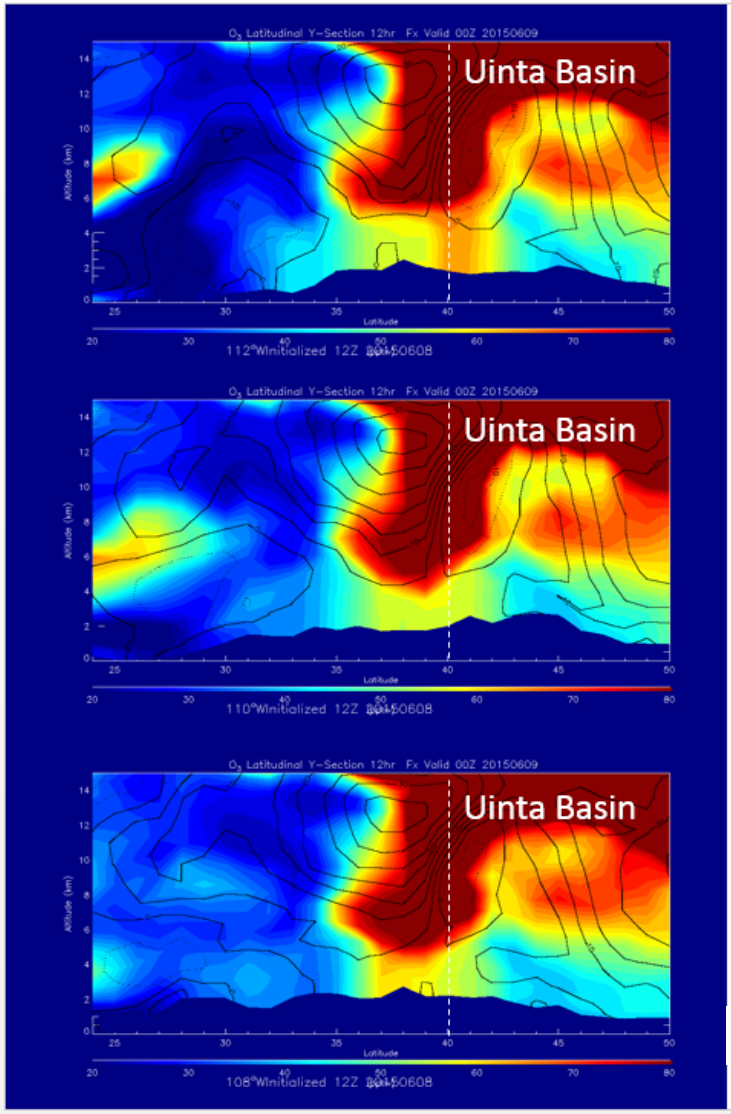
Clear Causal Relationship: Chemistry Models: RAQMS O_3 at 3 km, June 8, 2015, 5:00 am MST



Brad Pierce, NOAA, RAQMS PI

112W 110W 108W

Clear Causal Relationship: Chemistry Models: RAQMS O_3 at 3 km, June 8, 2015, 5:00 am MST



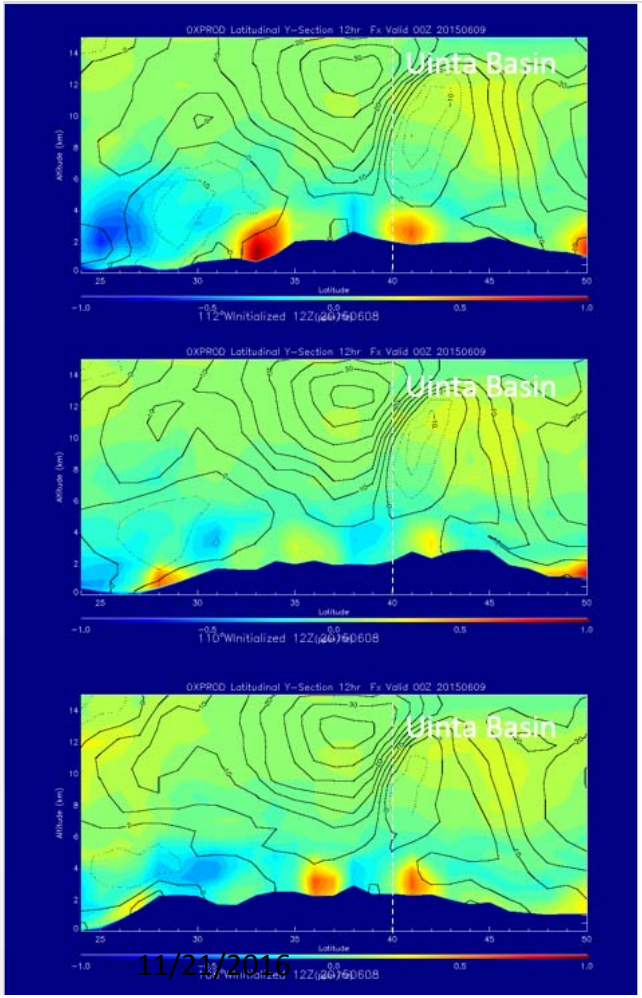
O3 Cross-section 112W
Salt Lake City/Phoenix AZ

O3 Cross-section 110W
24 miles W of Vernal, UT

O3 Cross-section 108W
80 miles E of Vernal, UT
55 miles E of Colorado Border

Brad Pierce, NOAA, RAQMS PI

Clear Causal Relationship: Chemistry Models: RAQMS Net Oxidant Production, June 8, 2015, 5:00 am MST



00Z June 9th, 2015

Net Ox Production Cross-section 112W
Salt Lake City/Phoenix AZ

Net Ox Production Cross-section 110W
24 miles W of Vernal, UT

Net Ox Production Cross-section 108W
80 miles E of Vernal, UT
55 miles E of Colorado Border

Fo Brad Pierce, NOAA, RAQMS PI

Clear Causal Relationship Summary

- Available observation data are consistent with a stratospheric intrusion impacting high elevation rural ozone monitors on June 8 and 9, 2015 in western Utah
  - Seasonal and diurnal ozone data
  - Total column ozone and CO
  - Upper air RH soundings
- Available model output confirm that a strong intrusions occurred over the impacted monitors, with modeled stratospheric ozone reaching ground level
  - NAM IPV and RH
  - GEOS-Chem and RAQMS ozone

Natural Event, Not Reasonably Controllable or Preventable

- Stratospheric intrusions are clearly natural events
- The intrusion is therefore not controllable or preventable
  - A demonstration can state those as facts, if the evidence that the event occurred with a clear causal relationship to exceedances is persuasive

Concluding Remarks

- Ongoing Stratospheric Intrusions Workgroup
  - Open to Government Workers (Federal, State, Local, Tribal)
  - Emphasis on measurements and analytic tools useful for intrusion identification and evaluation
  - Meetings 3rd Tuesday of each month, 10:00 am Mountain Time
    - Nov. 22, Brad Pierce, NOAA RAQMS PI will present RAQMS analysis of June 4-8 SI impacts to the Great Basin National Park monitor
  - Gail Tonnesen, EPA Region 8 is coordinator
    - tonnesen.gail@epa.gov
- The EPA intends to develop guidance to aid in the development of demonstrations for stratospheric intrusions